

Detection of SUSY Signals in Stau Neutralino Co-annihilation Region at the LHC

R. Arnowitt*, A. Aurisano*, B. Dutta*, T. Kamon*, N. Kolev†, P. Simeon*,
D. Toback* and P. Wagner*

*Department of Physics, Texas A&M University, USA

†Department of Physics, University of Regina, Canada

Abstract. We study the prospects of detecting the signal in the stau neutralino ($\tilde{\tau}_1$ - $\tilde{\chi}_1^0$) co-annihilation region at the LHC using tau (τ) leptons. The co-annihilation signal is characterized by the $\tilde{\tau}_1$ and $\tilde{\chi}_1^0$ mass difference (ΔM) to be 5-15 GeV to be consistent with the WMAP measurement of the cold dark matter relic density as well as all other experimental bounds within the minimal supergravity model. Focusing on τ 's from $\tilde{\chi}_2^0 \rightarrow \tau\tilde{\tau} \rightarrow \tau\tau\tilde{\chi}_1^0$ decays in \tilde{g} and \tilde{q} production, we consider inclusive $\cancel{E}_T + \text{jet} + 3\tau$ production, with two τ 's above a high E_T threshold and a third τ above a lower threshold. Two observables, the number of opposite-signed τ pairs minus the number of like-signed τ pairs and the peak position of the di-tau invariant mass distribution, allow for the simultaneous determination of ΔM and $M_{\tilde{g}}$. For $\Delta M = 9$ GeV and $M_{\tilde{g}} = 850$ GeV with 30 fb^{-1} of data, we can measure ΔM to 15% and $M_{\tilde{g}}$ to 6%.

Keywords: Neutralino dark matter, Stau neutralino co-annihilation, LHC

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INTRODUCTION

Supersymmetry (SUSY) with R -parity invariance automatically gives rise to a candidate, the lightest neutralino ($\tilde{\chi}_1^0$), for the astronomically observed cold dark matter (CDM), deeply linking particle physics with cosmology. If SUSY is correct, the $\tilde{\chi}_1^0$ particles will copiously be produced at the LHC. With the recent WMAP measurement of the CDM relic density [1] along with other experimental results, the mostly allowed parameter space within mSUGRA [2, 3] is the stau-neutralino ($\tilde{\tau}_1$ - $\tilde{\chi}_1^0$) co-annihilation region [4]. We investigate the accelerator phenomena at the LHC.

SUSY SIGNAL IN THE CO-ANNIHILATION REGION

The co-annihilation signal is characterized by a narrow mass difference (ΔM) between $\tilde{\tau}_1$ and $\tilde{\chi}_1^0$ of about 5-15 GeV [5]. Thus if this striking near degeneracy between $\tilde{\tau}_1$ and $\tilde{\chi}_1^0$ is observed at the LHC, it would be a strong indirect indication that the $\tilde{\chi}_1^0$ is the astronomical CDM particle.

Focusing on τ 's from $\tilde{\chi}_2^0 \rightarrow \tau\tilde{\tau} \rightarrow \tau\tau\tilde{\chi}_1^0$ decays in \tilde{g} and \tilde{q} production, we first examine the visible mass ($M_{\tau\tau}^{\text{vis}}$) distributions with three choices of p_T^{vis} threshold values for events in an mSUGRA co-annihilation region ($M_{\tilde{g}} = 831$ GeV and $\Delta M = 5.6$ GeV for $\tan\beta = 40$, $\mu > 0$, and $A_0 = 0$) using ISAJET 7.69 [6]. Even with such a small mass difference, the

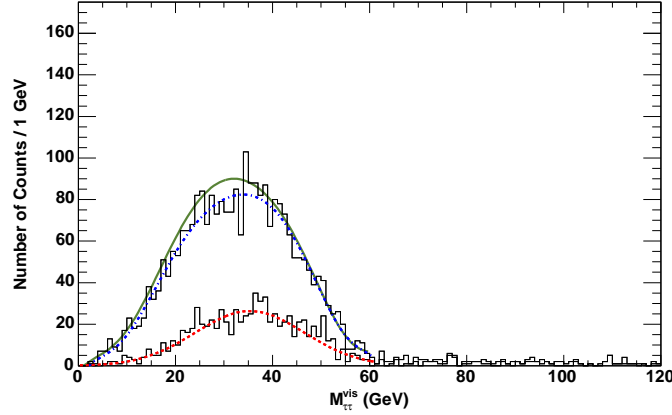


FIGURE 1. Visible di-tau mass distributions at a generator level for hadronically decaying τ leptons from $\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1 \tau \rightarrow \tilde{\chi}_1^0 \tau \tau$ in mSUGRA events ($\Delta M = 5.7$ GeV; the \tilde{g} , $\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$, and $\tilde{\tau}_1$ masses are 831, 264.4, 137.4, and 143.1 GeV, respectively). Three curves (solid, dash-dot, and dotted) are the distributions for τ 's selected with $p_T^{\text{vis}} > (20, 20)$, $(40, 20)$, and $(40, 40)$ GeV, respectively. Reconstructing τ 's with $p_T^{\text{vis}} > 20$ GeV is vital.

lower energy τ is boosted in the cascade decay of the heavy squark and gluino making it potentially viable with $p_T^{\text{vis}} \gtrsim 20$ GeV as shown in Fig. 1. We also note the end point of the mass distribution can be inferred from the figure, which is 62 GeV by

$$M_{\tau\tau}^{\text{end point}} = M_{\tilde{\chi}_2^0} \sqrt{1 - M_{\tilde{\tau}_1}^2 / M_{\tilde{\chi}_2^0}^2} \sqrt{1 - M_{\tilde{\chi}_1^0}^2 / M_{\tilde{\tau}_1}^2}.$$

From here on, we assume that both the ATLAS and CMS detectors can reconstruct and identify τ 's with $p_T^{\text{vis}} > 20$ GeV at an efficiency of $\varepsilon = 50\%$.

We consider two experimental final states: (a) $\cancel{E}_T + \geq 2$ jet + ≥ 2 τ events (2τ analysis) [5]; (b) $\cancel{E}_T + \geq 1$ jet + ≥ 3 τ events (3τ analysis) [7]. The signal in 3τ analysis occurs at a reduced rate, but with lower background. We calculate $M_{\tau\tau}^{\text{vis}}$ for every pair of τ 's in the event and categorize as opposite sign (OS) or like sign (LS). The mass distribution for LS pairs is subtracted from the distribution for OS pairs to extract $\tilde{\chi}_2^0$ decays on a statistical basis [8]. We note both final states will be triggered by requiring large E_T jet(s) and large \cancel{E}_T which will be available at the ATLAS and the CMS experiments.

Since two analyses use the same OS–LS technique, we only describe 3τ analysis in this paper, where the number of OS–LS τ pairs ($N_{\text{OS–LS}}$) and the peak position of the di-tau invariant mass distribution ($M_{\tau\tau}^{\text{peak}}$) are used for the simultaneous determination of ΔM and $M_{\tilde{g}}$.

We use ISAJET 7.64 [6] and PGS [9], and select events with at least one jet with $E_T > 100$ GeV and $\cancel{E}_T > 100$ GeV, followed by requiring at least two identified τ 's with $p_T^{\text{vis}} > 40$ GeV, additional one with $p_T^{\text{vis}} > 20$ GeV, and $E_T^{\text{jet1}} + \cancel{E}_T > 400$ GeV. Figure 2 is the mass distributions in the 3tau analysis, where we have assumed $\varepsilon = 50\%$ and a probability that a jet is misidentified as τ ($f_{j \rightarrow \tau}$) to be 1%. We see that the non- $\tilde{\chi}_2^0$ OS pairs are nicely canceled with the wrong LS combination pairs and that the OS–LS distribution is well fit to a Gaussian. We note that $M_{\tau\tau}^{\text{peak}}$ increase as the ΔM increases.

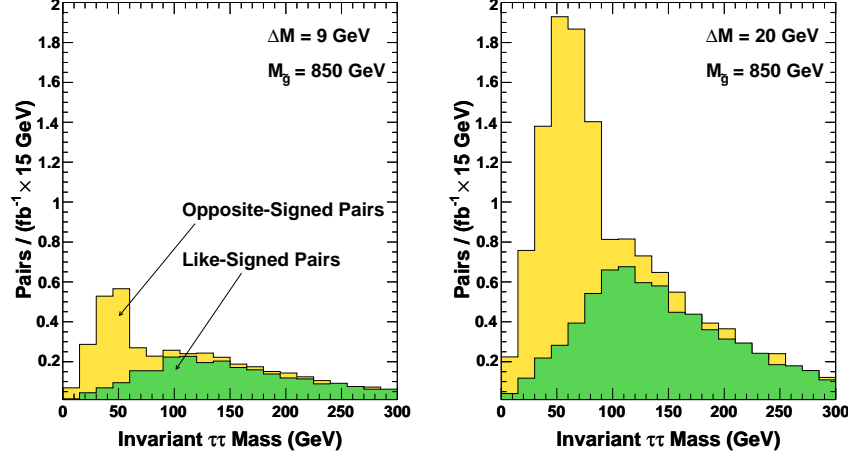


FIGURE 2. Visible di-tau invariant mass ($M_{\tau\tau}^{\text{vis}}$) distributions in the co-annihilation region ($\Delta M = 9$ GeV and 20 GeV) in the 3tau analysis with $\epsilon = 50\%$ and $f_{j \rightarrow \tau} = 1\%$.

Within mSUGRA models, $M_{\tau\tau}^{\text{peak}}$ changes with ΔM because the \tilde{g} , $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ masses are related. In the co-annihilation region, the squark masses largely depends on $m_{1/2}$, so that the production cross section (σ) is mainly as a function of $M_{\tilde{g}}$. The event acceptance (A) depends on ΔM and $M_{\tilde{g}}$. We parameterize $M_{\tau\tau}^{\text{peak}} = F(\Delta M, M_{\tilde{g}})$ and $N_{\text{OS-LS}} = \sigma(M_{\tilde{g}}) \cdot A(\Delta M, M_{\tilde{g}}) \cdot \mathcal{L}$. Here \mathcal{L} is a luminosity.

A correlation between the two functions allow us to measure $M_{\tilde{g}}$ and ΔM using $M_{\tau\tau}^{\text{peak}}$ and $N_{\text{OS-LS}}$. Figure 3 shows the contours of constant $N_{\text{OS-LS}}$ and $M_{\tau\tau}^{\text{peak}}$ for $\Delta M = 9$ GeV, $M_{\tilde{g}} = 850$ GeV, and $\mathcal{L} = 30 \text{ fb}^{-1}$. We find that for $\mathcal{L} = 30 \text{ fb}^{-1}$, we can measure ΔM to $\sim 15\%$ and $M_{\tilde{g}}$ to $\sim 6\%$. It is important to note, however, that our determination of $M_{\tilde{g}}$ is not a direct measurement, but a determination of the SUSY mass scale of the model. It will need to be compared to a direct $M_{\tilde{g}}$ measurement, assuming one is available. If the two results were consistent, it would be a consistency check of the gaugino universality of the mSUGRA model and that we are indeed in the co-annihilation region. Further, we expect that this analysis and the 2τ analysis could be used to complement each other in the establishment of a co-annihilation signal at the LHC, and perhaps be combined to produce a more accurate measurement.

CONCLUSION

We have demonstrated that if LHC experiments reconstruct/identify τ 's with $p_T > 20$ GeV with an efficiency in the 50% range, we could establish the signal in this co-annihilation region by detecting $\tilde{\chi}_2^0 \rightarrow \tau\bar{\tau}_1 \rightarrow \tau\tau\tilde{\chi}_1^0$. For our mSUGRA reference point of $\Delta M = 9$ GeV and $M_{\tilde{g}} = 850$ GeV, we can measure ΔM to 15% and $M_{\tilde{g}}$ to 6% with 30 fb^{-1} by simultaneously measuring the number of OS-LS di-tau pairs and the peak position of OS-LS di-tau mass distribution in the inclusive $\cancel{E}_T + \text{jet} + 3\tau$ final state.

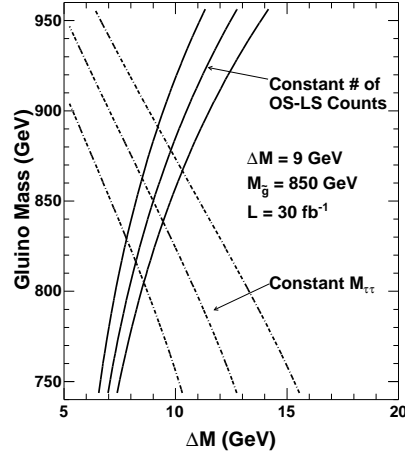


FIGURE 3. Contours of constant $N_{\text{OS-LS}}$ and $M_{\tau\tau}^{\text{peak}}$ for $\Delta M = 9$ GeV, $M_{\tilde{g}} = 850$ GeV, and $\mathcal{L} = 30 \text{ fb}^{-1}$. The middle lines are the central values while the outer lines show the 1σ uncertainty on the measurements. The region defined by the outer four lines indicates the 1σ region for the ΔM and $M_{\tilde{g}}$ measurements.

A 15% measurement of ΔM would generally be sufficient to determine if the signal is consistent with co-annihilation, and therefore, with the $\tilde{\chi}_1^0$ being the dark matter particle.

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